Selective use of duplex ultrasound to replace preoperative arteriography for failing arterial vein grafts

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Purpose: **In an effort to minimize costs and patient discomfort, we determined whether duplex ultrasound (DU) could selectively replace preoperative arteriography performed in the radiology suite to diagnose failing arterial bypass grafts (FABs) constructed of autogenous vein.**
Methods: **Between January 1, 1994, and December 31, 1996, we treated 106 FABs. Graft revision solely on the basis of DU was performed only if a focal stenosis was clearly identified in the graft (peak systolic velocity [PSV] >300 cm/sec, ratio of adjacent PSVs >3.0) or in inflow or outflow arteries (resulting in uniform graft PSVs <45 cm/sec). Intraoperative arteriograms were frequently obtained to confirm DU findings. Preoperative arteriograms were obtained if DU revealed multiple or ill-defined stenoses, diffuse inflow or outflow arterial disease, uniformly low PSVs without an identifiable lesion, or equivocal stenosis despite clinical evidence of an FAB.**
Results: **Seventy-three (69%) FABs with 81 lesions were revised on the basis of DU only. Of 76 stenotic lesions, an intraoperative arteriogram or surgical findings confirmed a diameter stenosis of 75% to 99% in 69 grafts (91%) and stenosis of 50% to 74% in three grafts (4%). DU incorrectly identified the site of stenosis or underdiagnosed the extent of disease in four grafts (5%). DU correctly identified the site of missed arteriovenous fistulas in five grafts. The 73 FABs were treated with intraoperative balloon angioplasty (30 grafts), patch angioplasty (20), interposition or jump grafts (12), ligation of arteriovenous fistula (3), a new bypass graft (1), or a combination of these interventions (7). A significant change in intraoperative strategy potentially could have been avoided if a preoperative arteriogram had been obtained in three of the 73 FABs (4.1%).**
Conclusions: **DU can reliably be used to revise FABs and avoid the morbidity, discomfort, and cost of confirmatory arteriography in two thirds of cases. (J Vasc Surg 1998;27:89-95.)**

Graft surveillance of failing peripheral arterial bypass grafts (FABs) has been shown to be worthwhile to prevent graft thrombosis and to enhance patency rates, as reported by Bandyk et al.[1-3] and others.[4-9] If graft thrombosis occurs, subsequent graft revision and patency rates have been shown to be markedly inferior compared with when a failing, but patent, graft is treated.[10] Diagnosis of a failing graft is made using clinical findings, segmental blood pressures, pulse volume recordings, and especially duplex ultrasound (DU). Traditionally, when a diagnosis of a failing graft is suspected by these methods, the finding is then confirmed by preoperative arteriography in the radiology suite (PRE-ART) before intervention is carried out to salvage the graft.

In the current health care market, cost-efficiency is emphasized but will not be achieved if safety or efficacy is compromised. In an effort to minimize patient discomfort, morbidity, and costs, we treated FABs on the basis of DU findings without confirmatory PRE-ART in selected cases and report the safety and reliability of this approach.

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PATIENTS AND METHODS

Between January 1, 1994, and December 31, 1996, we diagnosed 106 failing arterial grafts in 84 patients using a graft surveillance protocol performed in an accredited vascular laboratory.[3,11] There were 51 men and 33 women, with an average age of 71 years (range, 41 to 98 years).

Our graft surveillance protocol included clinical examination of the patient, segmental blood pressure and pulse volume recordings, and DU examination of the graft and inflow and outflow arteries. If there was suspicion of a failing graft, DU examination of the inflow arteries began at the infrarenal aorta whenever possible and extended as distally as the technologist could follow the outflow artery. DU criteria used to diagnose a focal stenosis in the graft included a peak systolic velocity (PSV) greater than 300 cm/sec or an adjacent PSV ratio greater than 3.0.[1-3,6,11] Criteria used to diagnose an inflow or outflow arterial stenosis included uniform PSVs less than 45 cm/sec throughout the graft with associated elevated PSVs at the arterial stenosis. DU also detected missed arteriovenous fistulas (AVFs) associated with in situ vein grafts by identifying arterial signals in venous tributaries of the greater saphenous vein and identifying the fistula site using B-mode imaging. FABs diagnosed using these criteria were then revised in the operating room without PRE-ART. DU findings were confirmed by intraoperative arteriograms obtained in the endovascular operating room before intervention or by surgical findings when the lesion was directly explored.

For patients treated only by surgical revision such as patch angioplasty at the stenotic site identified by DU, a preintervention arteriogram was not obtained (although postintervention completion arteriograms were routinely obtained). For patients who were treated with balloon angioplasty or for patients treated for multiple lesions, a preintervention arteriogram was obtained in the operating room via a graft or artery puncture removed from the suspected stenotic site. For a lesion proximal to a vein graft in the iliac artery treated with balloon angioplasty, the stenosis was confirmed by visualizing it first by a retrograde injection. For lesions in the body of a vein graft, the site of the injection for the arteriogram varied depending on the type of FAB. For reversed vein grafts that were tunneled anatomically, especially if they originated from the superficial femoral artery, the site of the antegrade percutaneous puncture was often the common femoral artery. For subcutaneous grafts (in situ grafts or translocated grafts tunneled superficially), the site of the open puncture was a different location in the body of the graft at least several inches removed from the stenotic site. For outflow lesions, the intraoperative arteriogram was performed as previously detailed (either via a common femoral artery or graft puncture, depending on the position of the graft). An intraoperative completion arteriogram of the entire graft was obtained in all cases to ensure a technically satisfactory repair and to rule out any other lesions in the graft.

Our technique to perform intraoperative balloon angioplasty was as follows. The type of intraoperative angiogram included use of a C-arm with digital tracking and memory. Intraoperative balloon angioplasty was performed after passage of a J-tipped hydrophilic guidewire through the stenotic lesion using an introducing sheath with a diaphragm manifold that limits blood loss with catheter exchanges. The diameter of the balloon was chosen to be 10% larger than the diameter of the adjacent normal diameter artery on the basis of the arteriogram. An insufflator with manometry was used to dilate the balloon until the wasting resolved but not exceeding balloon bursting pressures. Balloon angioplasty was performed for focal vein graft stenoses less than 2 cm in length that were in anatomically tunneled grafts, at an anastomosis, or separate from a surgically revised lesion. For lesions greater than 2 cm, vein interposition or jump grafts were performed. For isolated lesions in subcutaneous grafts, even those less than 2 cm, patch angioplasty or interposition grafting was performed usually with the patient under local anesthesia.

PRE-ART was obtained for FABs if DU (1) detected multiple or poorly defined stenoses that would require more than focal repair on the basis of the surgeon's interpretation of the study; (2) identified uniform low PSVs in the graft without an identifiable inflow or outflow lesion; (3) revealed diffuse inflow or outflow arterial disease; or (4) did not identify a problem, but clinical evidence of an FAB was present, such as diminished pulses or worsening ischemia.

RESULTS

Seventy-three FABs (69%) in 57 patients were revised on the basis of DU without confirmatory PRE-ART. During this period 33 grafts (31%) in 27 patients were revised on the basis of both DU and PRE-ART. Characteristics of both groups are listed in Table I.

Grafts revised on the basis of DU without PRE-ART. The treatment, type of anesthesia, and length of hospital stay for these 73 failing grafts are

listed in Table II. All interventions for this group of patients were performed in the endovascular operating room. A repair was performed without any preintervention intraoperative arteriogram only for selected single lesions treated with patch angioplasty or short jump or interposition grafts. This was the case in 27 of 35 potential cases.

Of the 81 lesions in these 73 grafts, a hemodynamically significant stenosis was suspected in 76 cases and missed AVF in five cases. Of the 76 stenotic lesions, a diameter stenosis of 75% to 99% was confirmed by intraoperative arteriogram or surgical findings in 69 lesions (91%) and a 50% to 74% stenosis in three lesions (4%). DU incorrectly identified two stenotic sites and underdiagnosed the extent of two stenoses for a total of four (5%) inaccurate identifications. The incorrectly identified stenotic sites were primarily a result of miscommunication between the technologist and the surgeon. The added morbidity in these two patients consisted of an additional small skin incision. The actual site of the stenosis was identified by intraoperative arteriogram before a graft incision was made. In a third patient the extent of stenosis in a failing common femoral–anterior tibial vein graft was underdiagnosed and the patient was inadequately treated with patch angioplasty only. The patient subsequently required an interposition graft 2 weeks later when follow-up DU revealed a persistent stenosis. In a fourth patient, the extent of disease in a failing femoropopliteal vein graft was underdiagnosed by DU. However, the intraoperative arteriogram before intervention revealed multiple lesions in the graft. The patient was treated by placing a new prosthetic femoropopliteal graft, which would have been the same operative strategy had PRE-ART been obtained. DU correctly identified the site of a missed AVF in all five cases. Therefore, intraoperative findings resulted in a significant change in surgical strategy (two extra skin incisions, one delayed operation with an interposition graft) that possibly could have been avoided if PRE-ART had been obtained in three of the 73 FABs (4.1%). However, it should also be noted that intraoperative, preintervention arteriograms were completely normal-appearing for three grafts revised on the basis of DU without PRE-ART (Fig. 1). The sites of the suspected stenoses were explored after intraoperative DU confirmed the presence of the lesions. In all three cases, thickened, retained valves that caused significant luminal compromise were discovered. The valves were excised and patch angioplasty performed. We believe that PRE-ART would not have detected the retained valves, and if the surgeon had acted only if the confirmatory PRE-ART showed a lesion, the grafts may have occluded.

Table I. Characteristics of FABs

	DU only (n = 73)	*DU + angiogram (n = 33)*
Initial arteriogram before intervention		
Within 1 mo	9	33 (repeat)
Within 1 to 3 mo	6	0
Within 4 to 6 mo	16	0
More than 6 mo	42	0
Type of bypass graft		
Femoroinfrapopliteal	34	14
Femoropopliteal	29	11
Popliteal tibial/pedal	10	8
Type of vein		
Greater saphenous	55	25
Arm	13	6
Lesser saphenous	5	2
Type of graft		
In situ vein	41	18
Reversed vein	22	13
Translocated vein	10	2
Site of lesions	(81)	(37)
Anastomosis	30 (37%)	13 (35%)
Proximal	(16)	(6)
Distal	(14)	(7)
Body of graft	34 (39%)	9 (24%)
Arteries	17 (21%)	15 (41%)
Inflow	(11)	(8)
Outflow	(6)	(7)
Common iliac	(5)	(2)
External iliac	(2)	(2)
Superficial femoral	(5)	(2)
Popliteal	(3)	(3)
Tibial	(2)	(6)

Of the 73 FABs treated on the basis of DU findings without confirmatory PRE-ART, five occluded (two treated with jump grafting, one with patch angioplasty, two with balloon angioplasty) and five required additional revision (three treated with patch angioplasty, one with valve excision, one with balloon angioplasty) within 1 month of the intervention for the failing graft, despite the fact that completion arteriograms obtained in the operating room showed technically excellent results in all cases. Other complications included a wound hematoma, that required surgical drainage at the puncture site after balloon angioplasty performed in the endovascular operating room, and pulmonary edema in a patient after undergoing patch angioplasty of a failing femoropopliteal bypass graft. None of the patients died during the first month after intervention.

Grafts revised with PRE-ART. Treatment,

Table II. Treatment of FABs

	DU only (n = 73)	*DU + angiogram (n = 33)*
Treatment		
Intraoperative ballon angioplasty	30	4
Patch angioplasty	20	3
Jump/interposition graft	12	14
Ligation of AVF	3	2
New bypass graft	1	4
Release of gastrocnemius	0	1
Exploration of dorsalis pedis	0	1
Combination of above	7	4
Balloon + patch	(5)	(3)
Ligation of AVF + patch	(2)	(0)
Balloon + jump graft	(0)	(1)
Type of anesthesia		
Local	47	5
Spinal/epidural	24	15
General	2	13
Hospital stay		
Outpatient	15	1
Discharged first day	39	8
Discharged after first day	19	24
Average length of stay (days)	1.4 (range, 0 to 8)	4.3 (range, 0 to 36)

type of anesthesia, and length of hospital stay for these 33 failing grafts are included in Table II. Interventions were performed in the endovascular operating room or occasionally in the radiology suite if only balloon angioplasty was required.

Of the 37 lesions in these 33 grafts, a hemodynamically significant stenosis was suspected in 35 cases and an AVF in two cases (two in situ vein grafts). Of the 35 stenotic lesions suspected by DU, a diameter stenosis of 75% to 99% or inflow or outflow arterial occlusion was diagnosed by arteriography performed in the radiology suite in 32 lesions (91%) and a 50% to 74% stenosis in three lesions (9%). PRE-ART was performed in one case to rule out any other lesions in addition to a missed AVF associated with an in situ vein graft. The patient ultimately required only AVF ligation.

Of the 33 FABs treated on the basis of DU findings with confirmatory PRE-ART, two occluded (balloon angioplasty of a femoropopliteal in situ vein graft and a distal jump graft of a femoropopliteal in situ vein graft), and three required additional revision (a missed valve, a missed AVF, and a missed kink in a graft, which were all detected by DU after PRE-ART) within 1 month of the intervention to salvage the failing graft. Other complications in this group of patients included: (1) rupture of a failing femoropopliteal in situ vein graft after balloon angioplasty performed in the radiology suite that required emergent surgical repair, which consisted of an interposition vein graft; and (2) a femoral nerve palsy after PRE-ART. None of the patients died during the first month after intervention.

The average length of hospital stay for patients who underwent these 37 graft revisions on the basis of DU findings with confirmatory PRE-ART was 4.3 days (range, 0 to 36 days). If the patient who was hospitalized for 36 days was excluded from analysis, then the average length of stay was 3.4 days (range, 0 to 9 days).

DISCUSSION

The results of this series of 106 failing arterial grafts suggest that DU can be used safely and reliably in a selective fashion to revise FABs without confirmatory PRE-ART in approximately two thirds of cases. Long-term follow-up and patency rates of FABs treated on the basis of DU findings alone or after confirmatory PRE-ART were not calculated because the point of this study was not to determine optimal intervention (balloon angioplasty, patch angioplasty, interposition graft, jump graft) for lesions that caused a failing graft but simply to assess whether intervention on the basis of DU findings was adequate without confirmatory PRE-ART.

Clinical judgment played a critical role in choosing an appropriate strategy for the FABs. In addition to the previously mentioned criteria to diagnose a failing graft, other factors helped determine the need for confirmatory PRE-ART. Contrast arteriograms obtained before the initial bypass procedure and intraoperative completion arteriograms after the initial bypass procedure was performed were carefully reviewed and heavily relied on in several instances. This approach was especially true for grafts that were diagnosed as failing within 1 month of their placement, and especially if DU findings were suspicious for an inflow or outflow arterial stenosis. Our results also point out the value of DU evaluation of inflow and outflow arteries because 33 of 118 lesions (28%) were present in these sites. The importance of well-trained vascular technologists in the setting of a dedicated, accredited vascular laboratory cannot be overemphasized when following this strategy. High-quality intraoperative digital fluoroscopic imaging that allows multiple views of the entire graft also enabled us to successfully adopt this protocol.

The majority of patients who underwent graft revision solely on the basis of DU findings required only local anesthesia and were discharged within 24 hours. We have previously demonstrated the value of clinical pathways and hospital cost savings for vari-

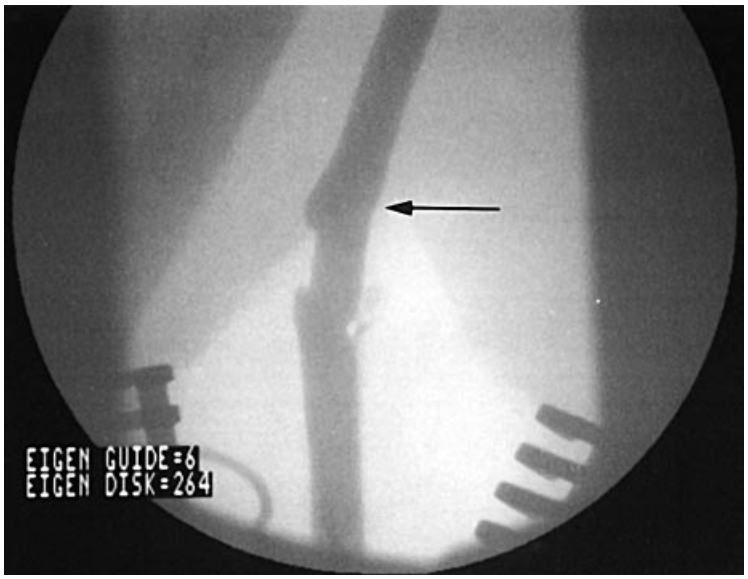

Fig. 1. Intraoperative, preintervention arteriogram in a patient with a failing common femoral–posterior tibial in situ vein graft as suspected by preoperative DU. Patient was brought to the operating room without a preoperative diagnostic arteriogram obtained in the radiology suite. Intraoperative DU confirmed a severe graft stenosis, as evidenced by high peak systolic velocities (400 cm/sec) that were not detected on the intraoperative arteriogram (*arrow*).

ous types of vascular surgery.[12] The strategy detailed in this report further delineates our philosophy for failing grafts. Despite the apparent cost savings, shorter length of hospital stay, and greater use of regional anesthesia in the group of patients who underwent graft revision on the basis of DU findings only compared with patients who underwent confirmatory PRE-ART, we are not suggesting that graft revision based solely on DU be adopted in all cases. Revision based on noninvasive testing without confirmatory PRE-ART was reserved for those grafts with focal lesions. Patients who underwent PRE-ART required this invasive study to better define the presence of multiple or long lesions, or diffuse inflow or outflow disease, as suggested by DU findings. Clearly, the group of patients who underwent PRE-ART required more extensive revision of their FABs, as evidenced by the smaller number of grafts revised by balloon angioplasty, the greater number of patients who required general anesthesia, and the longer length of hospital stay compared with patients whose FABs were revised on the basis of DU findings only.

Aside from the issue of cost savings, arteriography is associated with a small but real incidence of puncture site hematoma, contrast toxicity, and patient discomfort. Relying on DU findings alone can avoid these complications.

The results of this series showed that PRE-ART would have possibly resulted in improved outcome in three of the 73 bypass grafts revised solely on the basis of DU findings (4.1%). The patient who needed to be returned to the operating room within the first postoperative month because DU underdiagnosed the extent of stenosis most likely would have benefited from PRE-ART. Although two other patients had extra small skin incisions made over incorrect sites of a lesion, the potential trade-off was that the other 71 patients who did not undergo confirmatory PRE-ART in this series would have had groin punctures with the added discomfort and potential morbidity associated with those interventions. In addition, contrast studies can potentially miss retained valves, as in at least three of our patients.

CONCLUSION

These results demonstrate that when DU was performed in a high-quality, accredited, noninvasive vascular laboratory by well-trained technologists and was interpreted using sound clinical judgement by vascular surgeons, this noninvasive diagnostic tool can reliably be used to plan strategy to revise FABs. We are not suggesting that DU can replace arteriography in the radiology suite before initial lower extremity revascularization procedures, only that

confirmatory PRE-ART need not be performed in all, or even the majority, of FABs if DU identifies a focal lesion. In this era of minimally invasive intervention and concerns regarding patient comfort and medical care expenses, the approach outlined above can avoid the morbidity, discomfort, and cost of confirmatory arteriography in about two thirds of these patients.

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DISCUSSION

Dr. Dennis F. Bandyk (Tampa, Fla.). It is my pleasure to discuss this paper dealing with DU surveillance of lower limb bypass grafts. Dr. Calligaro and associates report a 3-year experience using duplex scanning to identify and guide the treatment of the failing graft. In two thirds of the 116 bypass grafts treated, graft revision was based on DU findings alone. No confirmatory arteriogram was obtained. But at the time of graft revision, in an endovascular surgery suite, the majority of the patients underwent a preliminary arteriogram; all patients had an arteriogram after intervention.

Important findings of the study were the low diagnostic error rate of duplex scanning, approximately 5%, and that the 30-day failure rate of the intervention procedures were similar for grafts revised on DU to those that had a confirmatory arteriogram. The authors estimated a cost savings of approximately $100,000 over this 3-year time period.

I think the strategy for dealing with the failing graft recommended by Dr. Calligaro is reasonable. It takes advantage of the lower morbidity and cost savings of duplex scanning, but as they have described it, requires the availability of an endovascular surgery suite. I do not believe the authors have used the full diagnostic potential of duplex scanning. Many decisions regarding the nature and treatment options for graft revision were not made until the arteriogram was obtained before revision, and thus the Philadelphia clinical pathway for the failing graft is most relevant for the surgeons who do their work in a surgery suite and have the catheter skills to perform balloon angioplasty. I have relied on duplex scanning to select patients for balloon angioplasty before getting to any type of intervention suite, relying on the diameter of the vein, the appearance time, and some other DU characteristics of a high-grade stenosis.

I believe the important elements of graft revision for stenosis, regardless of how the lesions are identified, is that when the lesion is treated the hemodynamic abnormality is corrected. A verification of this end point is best done also at the time of graft revision using duplex scanning. We have found that in approximately one third of the graft lesions that we have selected to balloon angioplasty, despite a good angiographic result a hemodynamic impairment remained and addition intervention was required.

I agree that arteriography is helpful in decisionmaking in about one quarter to one third of the patients, that is, those who have extensive graft lesions, low-flow grafts without any obvious abnormality, or patients who have persistent or residual foot ischemia despite a patent graft.

Dr. Calligaro, I would appreciate your thoughts in two areas. Given your experience with duplex scanning, why wasn't this method used at the time of graft revision rather

than emphasizing the use and importance of the completion angiogram as you do in the manuscript?

Second, the early graft failure rate of the graft revision procedure was considerable, 14% in the DU group and 15% in the group that also had a preintervention arteriogram, giving an overall 30-day failure rate of 15% in both groups. This early failure rate should be less than 5%, particularly when you're dealing with focal lesions. Do you think too many angioplasty procedures were performed, especially for graft lesions that appeared early after bypass grafting?

Dr. Keith D. Calligaro. Thank you, Dr. Bandyk. Your work was really the impetus for us adopting this strategy. Based on some of your suggestions, we have recently begun performing completion intraoperative DU scanning for all vein grafts in the operating room.

In answer to your second question concerning the relatively low patency rates after graft revision, we were somewhat disappointed by that finding. I believe part of it was a result of the fact that many of our grafts were revised a rather long time after they had been originally placed. And in many of these grafts, these were last-ditch efforts to revise the grafts. Either the entire vein was somewhat small diameter or the outflow was very limited, and this was our last chance to save the grafts.

Dr. George Andros (Encino, Calif.). I am wondering whether you made the calculation, using your own numbers and your own costs, of the outcome if those 34 patients received only balloon angioplasty? If the patients had gone to the special procedures room for balloon angioplasty and an angiogram and then been sent home in 4 hours, as you described, then half the people would not have had to be taken to the operating room, with its attendant costs and risks.

Dr. Calligaro. Dr. Andros, that's a very insightful point. What Dr. Andros is getting at is that many of our patients were treated with balloon angioplasty in our operating room. If they had just gone to the angiography suite and undergone balloon angioplasty at that time, then our proposed cost savings would not nearly be as dramatic, and that's a good point.

There are two points I'd like to make. First, if the balloon angioplasty does not result in a really excellent outcome and if you do it in the operating room, you can revise it right then and there. But the other point I want to emphasize is that after recently reviewing our data of balloon angioplasty for failing vein grafts, we have been pretty disappointed. And we are considering changing our strategy, as many other authorities have, because balloon angioplasty for vein grafts does not seem to yield very good long-term results. So we're being much more aggressive about revising these failing grafts surgically, so therefore our cost savings will be dramatic.

Dr. Samuel S. Ahn (Los Angeles, Calif.) I rise to concur with Dr. Calligaro's report. I have had similar results that I hope to report in the near future. But I do have one question to ask. The validity of the pathway you describe really depends on the long-term results as well as the immediate results. Do you have any follow-up data on your patient cohort to see whether your long-term results are as good as what they might have been had you pursued the traditional pathway of preoperative diagnostic angiogram?

Dr. Calligaro. We did compare our short-term results between the groups that underwent a preoperative formal arteriogram in the radiology suite with those taken directly to the OR on the basis of DU findings alone. As Dr. Bandyk alluded to, there were really no differences in those patency rates. We did not address our long-term patency rate because that was not the purpose of this study. But as I just mentioned, after recently reviewing our results for balloon angioplasty, we are starting to change our strategy and perform balloon angioplasty less because we have been disappointed by those results. Thank you very much.